PREDICTION OF INTER-PROVINCIAL TRADE FLOW TRAFFIC TO SUPPORT MULTI-CRITERIA PAVEMENT MANAGEMENT

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Introduction

Transport infrastructure has significant association with regional economy by generation economic activities through construction, rehabilitation and maintenance of transport infrastructure in the short term and by changing the spatial patterns of relative prices and production (Vickerman, 1987). The broader function of regional transport infrastructure can be categorized into two groups—transportation of people by passenger vehicles and transportation of goods by freight transports. Historically, freight travel demand has not been given adequate research interest by the regional planners, geographers and scientists comparing to the passenger travel demand. Freight travel demand was considered as the classic case of derived demand of economy and assumed that good prediction of economic outputs is sufficient enough to determine the regional transportation policy for freight transport (Vickerman and Monet, 2003).

Transport infrastructure components represent major capital infrastructure investments that must be protected in order to ensure adequate return on expenditure. The deterioration of transport infrastructure is progressive and is influenced by several factors including traffic axle loading, environmental condition, and original design and construction standards. Pavement maintenance is an essential function that should be implemented as soon as each stage of construction has been completed and should continue throughout the entire life of the structure. However, a well-planned maintenance operation is not only the function of accumulated traffic loads and environmental exposure during the life span of road infrastructure, but is also subjected to community benefits.

This study integrates the regional economy, land use, socio-economic factors with transportation to support the multi-criteria based pavement management system for regional road network of the Atlantic Canadian provinces—New Brunswick, Prince Edward Island, Newfoundland & Labrador, Nova Scotia and Quebec.

Methodology

This study predicts the interprovincial trade flow and freight movement during the period 2012-2041 by integrating spatial input-output model and transportation model. Pavement performance operations are determined based on the mechanistic modeling of roughness progression of the pavement surface. Finally, community development indicator of each road link is developed by multivariate analysis of the variables relevant to community development.

Spatial input-output modeling

The provincial capitals are considered as the points of origins and destinations of trade flow, as this study predicts the impact of interprovincial trade-flow on regional highways. This study applies TRANUS software (Modelistica, 2008), which estimates the interprovincial trade flow based on a spatial input-output model.

The spatial input-output model estimates the trade flow of goods and services for which the factors of production are private consumption, gross investment, government spending (both federal and provincial), and net exports. Gross investment includes non-residential investment (expenditure for firms for machines and tools), residential investment (expenditure by households and firms on apartments, buildings and factories), and change in inventories in a given period. Government spending consists of federal expenditure on provinces, provincial expenditure, and federal government transfers of funds to provincial governments. Net export is the summation of net international export (international export – international import) and net domestic export (domestic export – domestic import). Production of goods and services, and factors of production are included in the spatial input-output model as the sectors.

The fundamental assumption of spatial input-output model is that every sector requires input/production factors from other sectors except in the case of basic productive activities. Induced production at each province can be calculated given the amounts of final demand in one or more sectors of all other provinces, which is allocated among provinces through spatial distribution functions. The allocation of induced production among different provinces according to demand eventually causes flows of goods and services among different provinces through provincial road infrastructures.

The total demand for sector n in a particular province i (TD_i^n) is calculated by Equation 1 (Modelistica, 2008).

$$TD_i^n = \sum ID_i^{mn} + ED_i^n \; \forall \;\; ID_i^{mn} = \left(P_i^{n,t} = P_i^{n,t-1} + \Delta P_i^{n,t} * I_i^{n,t}\right) * PD_i^{mn} \quad (1)$$

$$PD_i^{mn} = PDmin^{mn} + (PDmax^{mn} - PDmin^{mn}) * exp - \delta^{mn} U_i^n \;\; \forall \;\; U_i^n = \frac{PD_i^{mn}}{[min\,(PD_i^{mn})]^{\theta^m}}$$

$P_i^{n,t-1}$ = Production of sector n in province i for time (t-1)
$\Delta P_i^{n,t}$ = Growth of production of sector n in province i between time (t-1) and t
$I_i^{n,t} = \frac{A_i^{n,t}}{\sum_i A_i^{n,t}}$ = Proportion of the increment of n allocated to province i for time t
$A_i^{n,t}$ = Attractor of sector n in province i for period t
ED_i^n = exogenous demand for n from zone other than five provinces and considered as zero
PD_i^{mn} = amount of production of sector n demanded by a unit of sector m in zone i
$PDmin^{mn}$ = minimum amount of n required by a unit production of m
$PDmax^{mn}$ = maximum amount of n required by a unit production of m

δ^{mn} = elasticity parameter of *m* with respect to the cost of input *n*
U_i^n = disutility of *n* in *i*
θ^m = degree of scaling. If utility function is fully scaled $\theta^m = 1$, otherwise zero.

The demand for production of good *n* in province *j* is the product of the total demand for *n* and the probability that the production of *n* in province *j* is demanded by other provinces (Equation 2) (Modelistica 2008).

$$P_j^n = \sum_i TD_i^n * Pr_{ij}^n \quad \forall \ Pr_{ij}^n = \frac{\left(A_j^n\right)^{\alpha^n} * \exp - \beta^n \tilde{U}_{ij}^n}{\sum_j \left(A_j^n\right)^{\alpha^n} * \exp - \beta^n \tilde{U}_{ij}^n} \qquad (2)$$

Pavement performance modeling
Pavement performance modeling is based on the mechanistic modeling of roughness progression (Paterson and Attoh-Okine, 1992; Watanatada et al., 1987). Equation 3 shows the mechanistic modeling of roughness based on initial as-built quality (*IRI_0*), the equivalent single axle load of predicted truck traffic for time *t* (*NE_t*), the observed pavement strength (structural number coefficient, *SNC*), and mean environmental exposure (Thornthwaite's moisture coefficients, *m*). As-built quality (*IRI_0)* is set between 0.7 and 1 m/km depending on the route and coefficient *a* was set to 265. The structural number coefficient (*SNC*) follows the formulation given by Watanatada et al. (1987). These values are taken as recommended by Amador-Jiménez and Mrawira (2011).

The mean environmental exposure is identified as 0.07, 0.074 and 0.08 (Paterson and Attoh-Okine, 1992) for the three environmental zones with a moisture index of 60, 80 and 100, correspondingly (Natural Resources Canada, 1995).

$$IRI_t = e^{mt}[IRI_0 + a(1 + SNC)^{-5} \cdot NE_t] \qquad (3)$$

Roughness (IRI) is rescaled to produce a 0 to 100 roughness index (PRI). Measures of rutting and linear cracking are combined to produce a surface distress index (SDI). Observed historical trends of structural strength (FWD and Dynaflect) are used to produce a structural adequacy index (SAI). These indexes are combined to produce a Pavement Condition Index (Amador-Jiménez and Mrawira, 2011).

The criteria of pavement treatments of the highways during the 30 years are presented in Table 1 (Mrawira and Amador, 2009).

Table 1. Treatment and operational windows used in network-level trade-off analysis

Treatment	**Operational Window**
Crack-sealing	IRI <= 1.13 and *Crack*[1] >= 90
Micro-surfacing (max. of 2 consecutive)	*Crack* >= 80 and *rutting*[2] <= 10%
Minor Rehab (e.g. thin overlay)	Arterial: IRI <= 2 and PSDI[3] >= 65
Major Rehabilitation	Arterial: IRI <= 2.5 and PSDI >=50
Reconstruction	IRI >= 2.0 SAI[4] <= 65

Notes: [1]CRACK = % of surface without cracks, [2]rutting = % of surface with rutting, [3]PSDI = pavement distress index, [4]SAI = structural adequacy index

Community Development Indicator

This study identifies 18 variables to calculate the Community Development Indicator of each Census Subdivision (CSD) of Atlantic Canada provinces. The variables are identified based on the community vulnerability report of Statistics Canada (Alasia et al., 2008). The variables are: total population, percentage of employment, income equality, percentage of agricultural employment, percentage of other primary employment, percentage of traditional manufacturing employment, percentage of distribution services employment, percentage of production service employment, proportion of participation in the labor market (ratio between experience labor force, 15+ and total population +15), percentage of working age population with post-secondary degree, percentage of individuals who moved from different CSD during last 5 years, proportion of average income for the population 15 years of age and over, concentration of immigrants, percentage of married population, proportion of young (<15 years), proportion of old (>65 years), and distance from large and small Census Metropolitan area (CMA). The variables are standardized in order to ensure the common unit.

Income equality is calculated from the Gini Index of income inequality. Gini Index is usually a standard economic measure of deviation from equal distribution of income among individuals and households within an economy based on Lorenz curve. Lorenz curve has drawn by plotting cumulative amount of income group and income in the X and Y-axis respectively). An economy that scores 0 on the Gini scale has perfect equality in income distribution. Higher the number over 0 indicates higher inequality, and the score of 1.0 indicates total unequal distribution of income. In this study, Gini Index measures the area (OAB) between Lorenz curve and the hypothetical line of absolute equality of income (Figure 1).

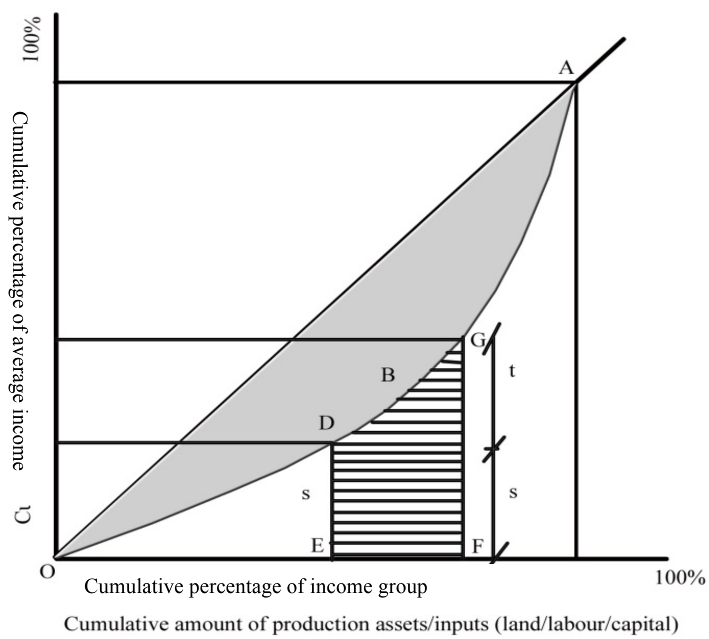

Figure 1: Lorenz curve of average income

The concentration of immigrants is calculated by the Herfindahl index (H-Index). This index, a measure of market concentration, is most commonly used by industrial organization economists and public-policy analysts. The H- Index of each CSD is the sum of square of the proportion of immigrants of different ethnic groups with respect to the total population.

This study applies the multivariate analysis technique to identify the variables of overriding importance for the complex problems under investigation along with the critical correlations (Mardia et al., 1979). Principal component analysis (PCA), a multivariate analysis technique, is applied to analyze the interrelationships among a large number of variables and to explain these variables in terms of their common underlying dimensions (Hair, 1992). PCA transforms the data to a new set of coordinates that are a linear combination of the original variables.

CDI for each CSD is calculated by multiplying the value of each variable for each CSD, the proportion of variance explained by each variables and the proportion of variance explained by each factor (under which that particular variable is loaded).

Prediction of Trade Flow and Freight Movement

The total demand and production of the five selected provinces for the period 2012–2041 are predicted based on the interprovincial trade flow data (1986–1996) collected from the Institut de la Statistique du Québec (Figure 2). Since the study is mainly concerned with the truck trade flow, the truck share of the interprovincial trade flow is incorporated during the calculation.

Figure 2 reveals that the predicted production and demand of goods and services in New Brunswick is indifferent during the period 2012-2041. In Nova Scotia, the total demand is decreasing while total production is increasing (increasing at an increasing rate until 2030 and then increasing at a decreasing rate) and demand is far lower than production during the same period. In Newfoundland and Labrador, the total demand exceeds total production during the estimation period. Production in Newfoundland and Labrador is exponentially increasing, while demand is linearly increasing. In Quebec, the total production is far higher than total demand and increasing at a higher rate than that of demand during the design period. In Prince Edward Island, the total demand is increasing at a higher rate than that of production.

The Annual Average Daily Truck Traffic (AADTT) for inter-provincial trade flow is estimated as 2397 for highway 1, 8008 for highway 2, 934 for highway 7, 599 for highway 15, 569 for highway 16, 226 for highway 102 and 183 for highway 104.

Pavement Maintenance Operations

The accumulated traffic loading, in equivalent single axle loads (NE_t), is calculated based on the predicted number of trucks per year (AADTT) and locally observed truck distributions combined with truck factors of 0.45, 1.18, 3.25, 0.99, 2.33, 5.91, 4.7 for truck classes 5, 6, 7, 8, 9, 10 and 13 respectively according to the Federal Highway administration classification (FHWA, 2011).

Pavement treatment activities, for the selected highways during the 30 years, are defined based on the operation window in Table 1. Table 2 represents the total length of the selected routes requiring different types of pavement treatments during the design period. Single chip sealing will be required for 15,261.1 km of selected routes, while 1952 km, 515.24 km, 383.3 km, 304.1 km and 84.28 km of highways require double chip sealing, micro-surfacing, minor rehabilitation, major rehabilitation and reconstruction respectively (Table 2).

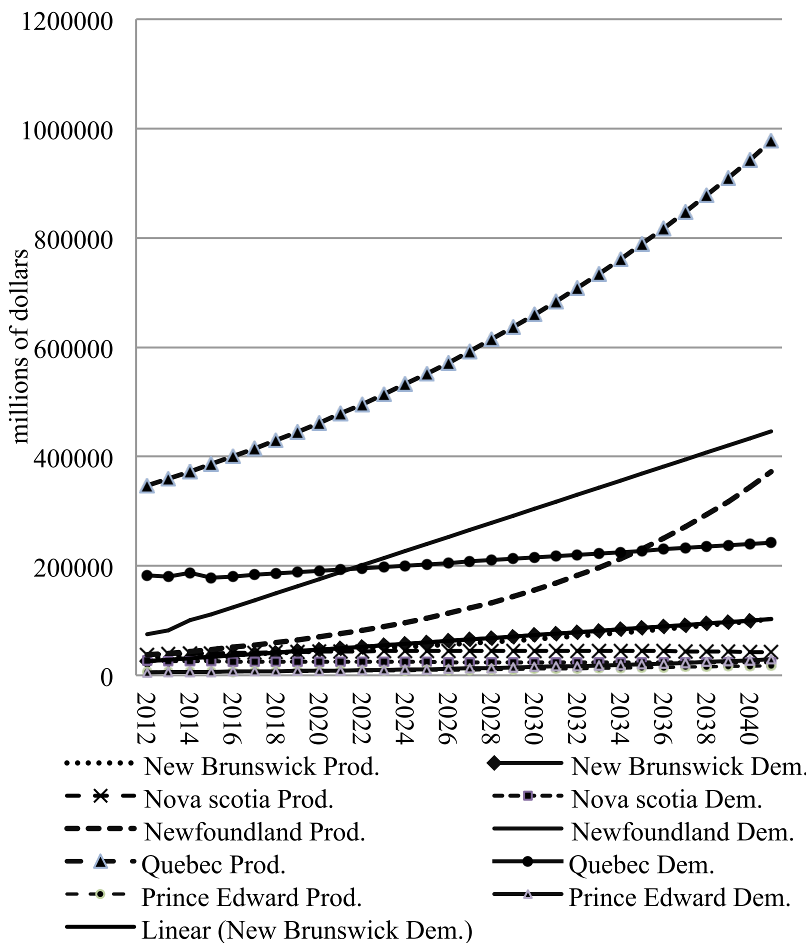

Figure 2. Total demand and production of five provinces during 2012-2041

Table 2. Pavement surface treatments of the length (km) of selected routes

Route	One cheap seal	Double cheap seal	Micro surfacing	Minor Rehab.	Major Rehab.	Recon
1	7073.7	246	18.68	11.48	168	5.44
2	1253.16	14.9	164.8	100.06	113.8	50.26
7	2246.26	1689.06	27.28	32.8	3.84	3.2
15	2985.06	0.56	100.14	58.24	4.36	5.1
16	1.44	1.48	2.64	5.18	6.96	14.48
102	3.68	0	121.22	126.76	1.8	5.8
104	1697.8	0	80.48	48.78	5.34	0

The Multivariate Analysis of Community Development Indicator

The first step of performing PCA is to assess the suitability of the data for principal component analysis. The pattern of relationships among variables is identified from the correlation matrix, the determinant of the correlation, the total variance explained (before and after rotation) and the component matrix (before and after rotation) of the variables.

The variables, which have strong correlation (±0.3 and above) with at least three variables, are considered as the significant variables for this multivariate analysis. Based on the correlation matrix of the final iteration process, this study confirms that all of variables of CDI are strongly correlated except for the percentage of population, the percentage of traditional manufacturing employment, concentration of immigrants, percentage of young people, and the distance from the large and small CMA.

The 'Eigenvalues' associated with each linear component (factor) before extraction, after extraction and after rotation are evaluated. The eigenvalue associated with each factor represents the variance explained by the linear component. If the total variance of each test is unity, the eigenvalue of the first factors extracted has a theoretical maximum equal to the number of tests (Kinnear and Gray, 2009). The first factors have the greatest sums and thus account for the greatest part of the total variance. The PCA reveals that the first 11 factors explain 97.57% of variance and have eigenvalues greater than 1. Finally, the rotated sum of squared loading, representing the effects of optimizing the factor structure, is examined in order to equalize the relative importance of the factors. The rotation sums of squared loadings indicate that 13.252% of the total variance is explained by the 1st factor, followed by 13.03% of the variance by the 2nd factor, 11.823% of the variance by the 3rd factor, 8.98% of the variance by the 4th factor, and 5.56% of the variance by the 5th factor.

The communality of each variable, which is the total proportion of its variance accounted for by the extracted factors, is calculated by the squared multiple correlations among the test and the factors emerging from the principal component analysis (Kinnear and Gray, 2009). The extracted column represents the common variance shared by the variables. For example, 95.1% of the variance associated with 'percentage of employment' is common or shared. The resulting communalities suggest that most of the selected variables describe the main characteristics of the CDI except the percentage of population, percentage of traditional manufacturing employment, proportion of young people, and distance from the large and small CMA.

After factor extraction, it might be difficult to interpret the factors on the basis of their factor loadings. The criterion used for the PCA indicates that the first factor accounts for the maximum part of the variance. This may often ensure that 'most variables have high loadings on the most important factor, and small loadings on all other factors' (Habing, 2003). Thus, the interpretation of the factors is very difficult. Factor rotation is conducted to alter the pattern of the factor loadings and to improve the interpretation. The process of rotation changes the eigenvalues of the factors that have been extracted, so that the common factor variance accounted for by the extraction is more evenly distributed among the rotation factors. By orthogonal rotation along the axes, it is possible to make clusters of variables load optimally. However, the communalities of the variables are unchanged by rotation, because their values depend only upon the number of factors and the correlations among the tests (Kinnear and Gray, 2009).

Table 3. Rotated component matrix of the variables for CDI

Variables of CDI	Rotated Component Matrix				
	1	2	3	4	5
Population distribution	-.02	.02	.07	.04	.06
Percentage of employment	-.09	.00	.96	.15	-.06
Income equality	.04	-.01	-.15	-.98	.04
Percentage of agricultural employment	.95	.04	-.01	.02	.01
Percentage of other primary employment	.95	.06	-.02	.00	.01
Percentage of traditional manufacturing employment	.09	.33	.14	.03	-.02
Percentage of distribution service employment	-.24	.58	-.10	.06	.02
Percentage of production service employment	-.32	.42	.08	.04	-.02
Proportion of participation in the labor market	.01	.03	.92	.13	-.03
Percentage of working age population with post-secondary degree	-.36	.62	.20	.05	.00
Percentage of individuals who moved from different CSD during the last 5 years	-.36	.62	.20	.05	.00
Average income	-.07	.01	.41	.76	.00
Concentration of immigrants	.00	-.03	-.05	-.09	.99
Percentage of married people	.35	.83	-.21	-.07	.01
Proportion of young	-.10	.02	.05	.02	.02
Proportion of old	.10	.52	-.09	.00	.03
Distance to large CMA	-.05	.01	-.01	.04	.01
Distance to Small CMA	-.03	.02	-.02	.03	-.01

The percentage of agricultural employment, percentage of other primary employment, proportion of young people, and distance from the large and small CMA are highly correlated with the 1st factor (Table 3). The percentage of traditional manufacturing employment, percentage of distribution service employment, percentage of production service employment, percentage of working population with post-secondary degree, percentage of individuals moved from different CSD during the last five years, percentage of married people, percentage of old population are highly associated with the 2nd factor (Table 3).

The variables such as percentage of employment, population distribution, proportion of participation in the labor market are comparatively more correlated with 3rd factor (Table 3). The income equality and average income are highly correlated with the 4th factor (Table 3). The concentration of immigrants, which is calculated by Herfindahl index, is highly correlated with the 5th factor (Table 3).

Thus the rotation of the factor structure clarified the relationships considerably. Five factors of CDI are extracted from 18 variables based on the multivariate analysis. These five factors explain 52.644% of the initial information.

Multi-criteria Index of Pavement Maintenance Operations

One of the main concerns of this study is to determine the significance or benefit of the road maintenance operations to community development. This can be determined by incorporating the 'Community Development Index (CDI)' of each CSD to the nearest road link. This study calculates the CDI of each road link by summing up the CDI of each CSD within the 5 km buffer zone of each road link (Figure 3). The 5-km distance, from the centroid of each CSD to the road link, is considered as the 5-km buffer zone of each road link.

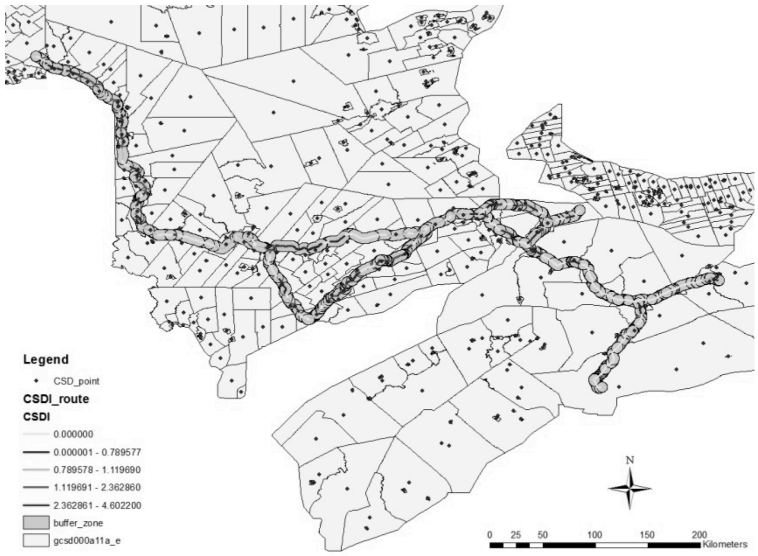

Figure 3. Community Development Index map of the regional road network

The prioritization of maintenance operations for each link of regional road network will not only be determined by the pavement condition and budget allocation but also equally by the CDI of each link.

Conclusion

Transport infrastructure has significant association with regional economy by generation economic activities. The deterioration of transport infrastructure is progressive and is influenced by traffic axle loading, environmental condition, and original design and construction standards. A well-planned maintenance operation is not only the function of accumulated traffic loads and environmental exposure during the life span of road infrastructure, but is also subjected to community development. This study predicts the interprovincial trade flow and freight movement during the period 2012-2041 by integrating spatial input-output model and transportation model.

Pavement performance operations are determined based on the mechanistic modeling of roughness progression of the pavement surface. Community development indicator of each road link is developed by multivariate analysis of the variables relevant to community development. The inclusion of community development index into the pavement maintenance operation can help the policy makers as well as transportation planner the positive impact of transport infrastructure maintenance on the community development.

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